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PATENT SPECIFICATION

DRAWINGS ATTACHED

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Sine wave generator.

COMPLETE SPECIFICATION

We, WESTINGHOUSE ELECTRIC CORPORATION, of Three Gateway Center, Pittsburgh 30, Pennsylvania, United States of America, a corporation organized and existing under the laws of the Commonwealth of Pennsylvania, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to apparatus for generating very low frequency signals electronically, and more particularly, to a means for generating very low frequency communication signals, that is under 50 kilocycles at high power levels with semiconductor devices such as silicon controlled rectifiers to generate sine wave power for operation at such very low frequencies of radio transmitters, for sonar apparatus and other apparatus operating at or near ultrasonic frequencies.

It is well known to those skilled in the art that the silicon controlled rectifier may be used in place of a thyratron gas control tube in a DC charged magnetic radar modulator. It has been observed that the silicon controlled rectifier is more reliable than a thyratron and is capable of generating peak pulse powers in the range of 2 to 20 megawatts. Basically, the silicon controlled rectifier is a PNPN switch and is capable of controlling a relatively large current with a small amount of power. It resembles a thyratron in operation in that once the device has been rendered conductive by a trigger signal applied to its gate electrode, control is lost until the current flow therethrough is reduced below its minimum sustaining current wherein the current stops and the device will remain in its nonconductive state until it is again triggered into conduction at a later time. Whereas the silicon controlled rectifier has been utilized in apparatus which generates high power pulses necessary to trigger microwave tubes, such as magnetrons, into oscillation there has not heretofore been any instance wherein the switching characteristics of the silicon control rectifier may be utilized to generate relatively high power sinusoidal wave shapes at very low frequencies.

The chief object of the present invention is to provide an apparatus for the generation of sinusoidal voltages, for use in communications apparatus, operating in the very low frequency region (VLF) and ultrasonic region of the electromagnetic spectrum and utilizing silicon controlled rectifiers to generate a high power sine wave source for a solid state transmitter.

The invention resides in a sine wave generator operating in the very low frequency range of the radio frequency spectrum comprising: a source of direct current, at least two semiconductor controlled rectifiers mounted in series between the poles of said source; control means for selectively rendering said semiconductor controlled rectifiers conductive; a pulse shaping network connected to the common point of connection of said semiconductor controlled rectifiers, and a resonant load circuit connected between said pulse shaping network and a point of reference potential, said control means being adapted to charge said resonant load from one pole of said source and one of said semiconductor controlled rectifiers over said pulse shaping network and to discharge said resonant load over the other of said semiconductor controlled rectifiers and the other pole of said source, said pulse shaping network matching the natural resonance characteristic of said load, whereby said load oscillates and generates said sine wave.

More specifically, means is provided for generating relatively high power sine waves at very low frequencies with silicon controlled rectifiers acting as PNPN switches to alternately charge and discharge a pulse forming

network which when discharged can deliver a pulse of electrical energy across its output terminals. A resonant load circuit, such as an underdamped parallel resonant tank circuit is coupled to the pulse forming network whereby the tank circuit is made to oscillate at its resonant frequency when the pulse forming network discharges a pulse of energy into it at predetermined intervals. The application of successive pulses from the pulse forming network will result in a smooth sinusoidal output signal of the resonant frequency of the tank.

In order that the invention may be understood more clearly and readily carried into effect, reference will now be made to the accompanying drawings, in which:—

Figure 1 is a schematic wiring diagram of one embodiment of the present invention, and

Fig. 2 is a schematic diagram of another embodiment of the present invention.

In Figure 1, there is shown two silicon controlled rectifiers 12 and 14 coupled to a pulse forming network 13 which has its output tied to a resonant load circuit 20. In greater detail silicon controlled rectifier 12 having an anode electrode 61, a cathode electrode 63 and a gate electrode 65 is connected in series with silicon controlled rectifier 14 having an anode 71, a cathode electrode 73 and a gate electrode 75. The controlled rectifiers 12 and 14 are coupled together such that they are connected in series between a source of DC electrical potential B+, not shown, and a point of reference potential hereinafter referred to as ground. The source of DC electrical potential B+ is connected to the circuit at terminal 28 which, in turn, is connected to the anode electrode 61 through a charging inductance 10. The cathode electrode 63 of silicon controlled rectifier 12 is connected to the anode electrode 71 of silicon controlled rectifier 14. The cathode electrode 73 is connected to ground completing the series circuit between the terminal 28 and ground. The gate electrodes 65 and 75 of silicon controlled rectifiers 12 and 14 are respectively connected to the secondary windings 42 and 52 of the transformers 40 and 50. The primary windings 41 and 51 are connected to the trigger generator 30 which provides suitable trigger pulses to the gate electrodes 65 and 75 for rendering the silicon controlled rectifiers 12 and 14 conductive at predetermined time intervals.

Coupled to the connection between cathode electrode 63 and anode electrode 71 is one side of the pulse forming network 13 at a junction 34. The other end of the pulse forming network is coupled to the resonant load 20, comprising a parallel tank circuit of an inductor 22, a capacitor 24 and a load resistor 26. Although the pulse forming network 13 is connected to the intermediate point of the inductance 22, it should be pointed out that when desirable the coupling may be tied to the upper end of the tank.

In operation, the embodiment shown in Fig. 1 is controlled by the trigger generator 30. First, silicon controlled rectifier 12 is actuated by means of a trigger signal applied to the gate electrode 65 rendering it conductive while silicon controlled rectifier 14 remains non-conductive. The pulse forming network 13 is resonantly charged to a voltage thereacross of twice the supply voltage by means of current flowing from the B+ supply voltage, not shown, through the charging inductor 10, the silicon controlled rectifier 12 and the portion of the resonant load 20 represented by the inductance 22 having one side connected to ground. The value of the inductance 10 is large in comparison to the inductance 22 and the equivalent inductance exhibited by the pulse forming network 13. The pulse forming network comprises one inductance and a capacitance. The pulse forming network 13 charges to approximately twice the value of the B+ supply voltage in a time equal to $\pi\sqrt{LC}$ where L is the value of the charging inductance 10 and C is the value of the capacitance exhibited by the pulse forming network 13. As the pulse forming network 13 becomes charged, the current flow through silicon controlled rectifier 12 decreases and eventually falls to a value which is less than the sustaining current of the device and it becomes non-conductive and remains non-conductive until subsequently triggered by a signal applied to its gate electrode 65. At a predetermined later time, the trigger generator 30 applies a trigger pulse to the gate electrode 75 of silicon controlled rectifier 14 rendering it conductive, whereupon the charge accumulated by the pulse forming network very rapidly discharges through the resonant load 20 in the form of a relatively sharp pulse of electrical energy. It should be noted that the use of silicon controlled rectifier 12 in the charging path of the pulse forming network 13 enhances the operation of the discharging circuit in that it allows substantially complete discharge of the pulse forming network, whereas if an ordinary charging diode were utilized in place of controlled rectifier 12, it would become conductive as soon as the voltage across the pulse forming network fell below the value of the B+ voltage, thus limiting the repetition frequency of operation and/or the pulse width of the energy pulse fed to the resonant load 20. The resonant load 20 comprising the parallel arrangement of the inductance 22, the capacitor 24 and the load resistor 26 is designed as a high Q tank circuit and is underdamped such that upon receiving the pulse of energy from the pulse forming network 13 during its discharge the tank circuit will ring or oscillate at its resonant frequency

f_0. By successively triggering silicon controlled rectifiers 12 and 14 alternately at periodic intervals, for example every cycle of the output frequency f_0, the resonant load 20 can be made to sustain oscillations at its resonant frequency to provide a smooth sinusoidal output.

It should be noted that the resonant load 20 is shown by way of an example only and it may be representative of the equivalent circuit of a radiating antenna system such as might be utilized in combination with the power output stages of a radio transmitter. Also, the resonant load 20 may represent the output circuit of a sonar or other ultrasonic device thus having an output frequency in the ultrasonic frequency range.

It should also be pointed out that the charging inductance 10, as illustrated in Fig. 1, might be included in the pulse forming network such that the pulse forming network 13 may comprise simply a single inductor in series with a capacitor and having the inductor serving as both the resonant charging inductor and the pulse forming inductor.

It is well known that silicon controlled rectifiers once having become conductive require a finite recovery time before being reactivated once they subsequently become non-conductive. The reason why the finite recovery time is associated with these devices is due to minority carrier storage occurring across the end junctions during conduction. These carriers require a definite length of time to be collected. The length of storage time is essentially a function of the peak forward current and the rate of change of current through the rectified. For this reason, the minority carrier storage effect must be taken into account when a relatively fast operation is required as it would affect the upper frequency limit.

In order to develop a relatively higher power output sine wave across the resonant load 20 with the same type of silicon control led rectifiers as utilized in the embodiment of Fig. 1, an embodiment such as shown in Fig. 2 may be employed. Whereas the embodiment in Fig. 1 employed a single silicon controlled rectifier 12 to charge the pulse forming network 13 and utilized another single silicon controlled rectifier 14 to discharge the pulse forming network, the embodiment illustrated in Fig. 2 comprises a plurality of silicon controlled rectifiers for charging the pulse forming network 13, and also a plurality of silicon controlled rectifiers for discharging the pulse forming network. More particularly, this embodiment illustrates a first three sets, comprising pairs of silicon controlled rectifiers 12*a* and 15*a*, 12*b* and 15*b*, and 12*c* and 15*c* connected in parallel between one end of a charging inductor 10 and junction point which, in turn, is coupled to one side of the pulse forming network 13. The pulse forming network 13 here is shown comprising an inductance 16 and a capacitance 18 in series. Connected between junction 34 and ground is another three sets, comprising pairs of silicon controlled rectifiers, 14*a* and 17*a*, 14*b* and 17*b*, and 14*c* and 17*c*. Both three sets of silicon controlled rectifiers form three stages A, B and C which operate into the pulse forming network 13 in a manner to be subsequently described. Associated with each silicon controlled rectifier is a transformer winding for respectively rendering each silicon controlled rectifier of a set selectively conductive simultaneously. For example, the controlled rectifiers 12*a* and 15*a* are connected in series and are operated as a single unit in order that the voltage applied to terminal 28 can be increased without exceeding the peak inverse voltage rating (PIV) of the controlled rectifiers. It should be understood that the invention is not meant to be limited to a pair of silicon controlled rectifiers such as 12*a* and 15*a*, but any number may be connected in series depending upon the magnitude of voltages employed. The same can be said for the series combination of silicon controlled rectifiers 14*a* and 17*a* in that any number of silicon controlled rectifiers may be operated in series.

In operation the stages A, B and C are operated sequentially so that the average current through any one set is reduced so that a relatively larger overall current can be fed into the pulse forming network without exceeding the current rating of any one controlled rectifier. More particularly, silicon controlled rectifiers 12a and 15a are rendered conductive simultaneously to charge the pulse forming network 13 from a source of B+ battery potential, not shown, applied to terminal 28 and through the charging inductor 10. Just as in the case of the embodiment, shown in Fig. 1, the charge on the pulse forming network 13 rises to approximately twice the value of the supply voltage applied to terminal 28 in the form of a charge placed upon the capacitor 18. Again as the capacitance 18 charges, the magnitude of the current flow through the silicon controlled rectifiers 12*a* and 15*a* decreases until the minimum sustaining or holding current is reached at which time they become non-conductive. During this first interval, the silicon controlled rectifiers 14*a*, 17*a* and all of the other silicon controlled rectifiers in stages B and C remain non-conductive. During a second interval of time, silicon controlled rectifiers 14*a* and 17*a* are simultaneously rendered conductive allowing the pulse forming network 13 to discharge rapidly to deliver a pulse of energy to the resonant load 20 causing it to oscillate at its resonant frequency f_0.

The combination of stages A, B and C, each comprising two sets of silicon controlled

rectifiers, is utilized such that after stage A has charged and discharged the pulse forming network 13, stage B is directed to charge and discharge the pulse forming network in a manner as described for stage A. Likewise, after stage B has performed a charging and discharging operation, stage C is activated to do likewise. In this manner, stages A, B and C operate in a predetermined sequence to continuously deliver pulses of energy to the resonant load 20 while allowing the previously activated stages to recover before being retriggered. By sequentially operating stages A, B and C each stage carries only 1/3 of the total current fed to the pulse forming network 13. Therefore, the embodiment of Fig. 2 can handle three times the current that the embodiment of Fig. 1 can deliver without exceeding the current rating of the silicon controlled rectifiers. Whereas, in Fig. 1, energy was delivered to the resonant tank circuit each cycle by only one pair of silicon rectifiers, the embodiment of Fig. 2 operates such that each set of silicon controlled rectifiers is only required to work every third cycle. It should be understood that any number of stages (A to N) can be used depending upon the one practising the invention and they may be operated in parallel or any combination thereof.

By sequentially charging and discharging the pulse forming network 13, using multiple stages, a higher power can be built up in the resonant load 20 and a purer output sine wave voltage including increased power can be obtained.

WHAT WE CLAIM IS:—

1. A sine wave generator operating in the very low frequency range of the radio frequency spectrum comprising: a source of direct current, at least two semiconductor controlled rectifiers mounted in series between the poles of said source; control means for selectively rendering said semiconductor controlled rectifiers conductive; a pulse shaping network connected to the common point of connection of said semiconductor controlled rectifiers, and a resonant load circuit connected between said pulse shaping network and a point of reference potential, said control means being adapted to charge said resonant load from one pole of said source and one of said semiconductor controlled rectifiers over said pulse shaping network and to discharge said resonant load over the other of said semiconductor controlled rectifiers and the other pole of said source, said pulse shaping network matching the natural resonance characteristic of said load, whereby said load oscillates and generates said sine wave.

2. A sine wave generator as claimed in claim 1, wherein said pulse shaping network is resonantly charged to substantially twice the voltage of said source when one of said controlled rectifiers is rendered conductive, and wherein said control means is adapted to alternately control the conduction of said two controlled rectifiers for rendering the same selectively conductive at mutually different time intervals in order that electrical energy might be transferred to said pulse shaping network during a first time interval and discharged during a second time interval; the oscillations of said resonant load circuit resulting from energy transfer from said pulse shaping network as said pulse shaping network is discharged during said second time interval.

3. A sine wave generator according to claim 2, wherein at least another pair of semiconductor controlled rectifiers is provided, connected in parallel with said source and the first-mentioned pair of semiconductor controlled rectifiers, the two pairs being connected in the same fashion to said pulse shaping network and said resonant load, said control means being adapted to switch on and off the respective rectifiers of each pair during the corresponding said first and second time intervals, thereby to sequentially charge and discharge said resonant load over said pulse shaping network.

4. A sine wave generator according to claim 3, wherein in each of said pairs each of said semiconductor controlled rectifiers is replaced by at least two semiconductor controlled rectifiers connected in series between the corresponding pole of said direct current source and said common point of junction between semiconductor controlled rectifiers, said control means rendering selectively conductive the said series connected semiconductor controlled rectifiers, concurrently, during the respective said first and second time intervals.

5. A sine wave generator according to any preceding claim, wherein each of said semiconductor controlled rectifiers is a PNPN switch.

6. A sine wave generator according to any preceding claim, wherein said pulse shaping network comprises a series resonant capacitor inductor circuit.

7. A sine wave generator substantially as hereinbefore described with reference to, and as illustrated in the accompanying drawings.

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1,042,269 COMPLETE SPECIFICATION

1 SHEET

This drawing is a reproduction of the Original on a reduced scale.

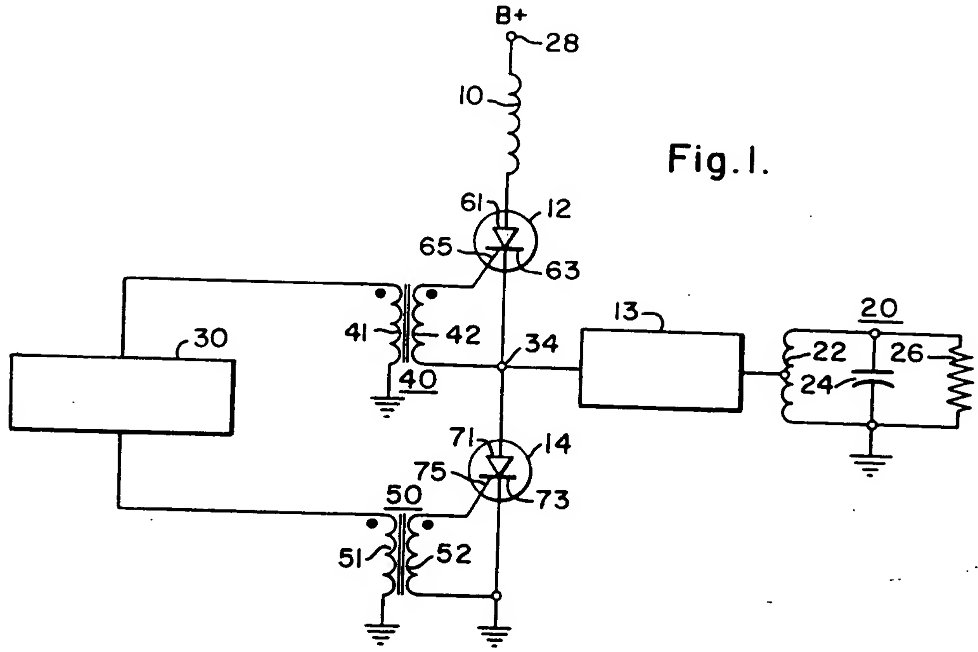

Fig. 1.

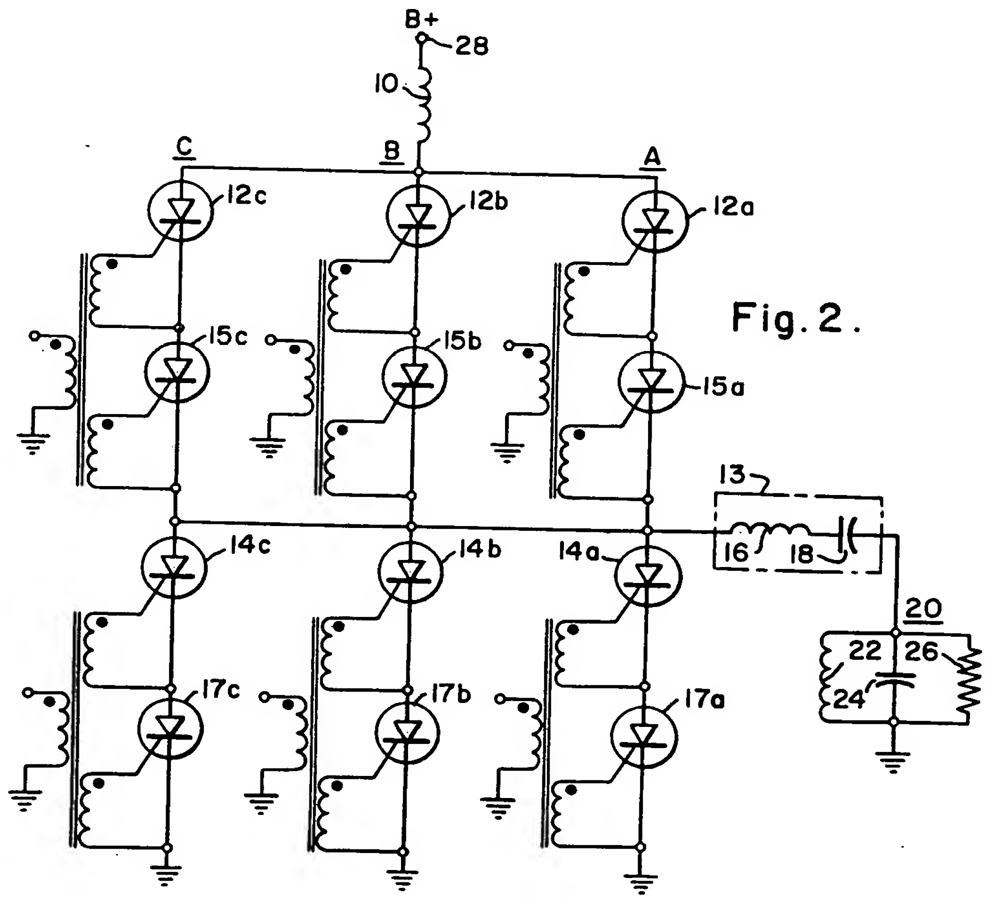

Fig. 2.